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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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For the President of the European Patent Office

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Multi-layer writable optical record carrier with an optimum power calibration area, and method and apparatus using with such a record carrier

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Multi-layer writable optical record carrier with an optimum power calibration area, and method and apparatus using with such a record carrier

The present invention relates to a writable optical record carrier, and particularly to a recordable WORM- or RW-disc, comprising a plurality of recording layers separated by a spacer material, each recording layer comprising an optimum power calibration (OPC) area. It further relates to a method and an apparatus for forming optimum power calibration areas on such a writable optical record carrier.

The ever-increasing demand for data storage capacity has resulted in the development of high-density optical recording media such as write once or re-writable DVD discs and Blue-ray Disc (BD) discs. In these cases, data capacity has been increased by increasing the numerical aperture (NA) of the objective lens and by reducing the wavelength of the recording/reading laser light.

A complementary approach to obtain high storage capacities is to increase the number of recording layers. For example, by introducing n information storage layers, an n-fold increase of data-capacity is obtained. This latter approach is currently followed for DVD+R, DVD+RW, BD-R, and BD-RW media. Two-fold increase (in a dual-layer disc) is known, while four-fold increase (in a quadruple-layer disc) is being investigated.

There are two main different writing principles presently known: dye recording in case of write once media such as CD-R, DVD+R and DVD-R, and phase-change recording in case of rewritable media such as CD-RW, DVD-RAM, DVD-RW, DVD+RW, and BD-RW.

Phase-change recording layers commonly comprise a phase-change material that is typically an alloy with a durable polycrystalline structure sandwiched in a stack between two dielectric ZnS-SiO_2 layers. The energy of a writing laser beam, modulated by a recording signal, which is irradiated onto the record carrier will to a large extend be absorbed by the phase change material, thereby inducing a phase changes from a crystalline phase into an amorphous state. Whereas the crystalline phase (ground state) has a high reflectivity, the amorphous phase (written state) has a reduced reflectivity. Therefore, the recording layer reflects a reading beam focused on said recording stack with different intensities depending on whether it strikes a written area (mark) or an unwritten area (land).

Dye recording layers are typically composed of an organic dye layer comprising dye materials, such as for example cyanine, phthalocyanine or metallized azo, and a reflective metal layer, typically made of gold, silver, or aluminum. A writing laser beam will be partially absorbed by the recording layer, thereby durably and irreversibly bleaching and decomposing the dye material. A reading beam striking a mark written in that manner will be partially scattered by that mark. Consequently, the intensity of the light reflected at the reflective metal layer depends on whether the reading beam strikes a mark or passes the recording layer almost undisturbed.

In this way, the recording status of a layer induces a change in the average reflection of the layer and also affects its transmission. In case of a multi-layer disc, this means that the reading and writing on one appointed (in-focus) layer generally is influenced by the presence of the other (out-focus) layers in the disc. Stray-light generated at the out-focus layers is proportional to their average reflection within the NA of the objective lens, in turn depending on the presence of marks (representing data) in the out-of-focus layers in that region. Furthermore, the presence of data in the out-focus layers results in different transmission properties of those layers. Hence, when the laser beam passes one or more layers, the optical power that is received by the in-focus-layer is altered and different optimum conditions (that is, write-power, focus-offset, etc.) may be obtained depending on whether or not the surrounding layers contain data within the NA of the objective lens.

It is commonly known that in order to obtain the best quality of the recorded data on an optical disc, the drive performs an optimum power calibration procedure (OPC) prior to the recording process. From this OPC-procedure, the drive determines the optimum power for recording the data. In general, this OPC procedure is performed every time a disc (either blank or partially recorded) is inserted in the drive. For a multi-layer optical disc, the outcome of the OPC procedure for one layer may depend on the presence of data in the other layers.

In order to avoid a poor quality of the recorded data in multi-layer optical discs, these effects have to be accounted for. In European Patent Application 1244096, a disc having plural recording layers each with OPC-test areas is suggested. These OPC-test areas comprise portions with the highest power transmittance path and portions with the lowest power transmittance path. However, in such a disc, space occupied by these OPC-test areas is very large.

It is an object of the present invention to provide a writable optical disc with a plurality of recording layers, wherein optimum power calibration areas are provided being efficient with respect to the calibration of the optimum writing power for the most preferred writing strategies, thereby requiring minimum space. It is a further object to provide a method and an apparatus for forming optimum power calibration areas on such a writable optical record carrier.

According to a first aspect of the present invention this object is achieved by a writable optical disc for use in a recording device with an objective lens having an aperture NA, said disc comprising a plurality of recording layers L0,…, Ln-1 separated by a spacer material, each of the recording layers comprising an optimum power calibration area, whereby at least the optimum power calibration areas of the layers L0,…, Ln-2 or L1,…, Ln-1 have a first portion with an average reflection value representative for a recorded layer, the optimum power calibration areas of each recording layer L0,…, Ln-1 have a second portion with an average reflection value representative for an unrecorded layer, and said optimum power calibration areas partially overlap in such a way that the first portions of each pair of subsequent recording layers Lk, Lk+1 form a step with a minimum step size $w_{k,k+1}$ of

$$w_{k,k+1} = 2\varepsilon + \frac{NA}{\sqrt{n_m^{\ 2} - NA^2}} \cdot \Delta_{k,k+1}, \qquad (1)$$

wherein ε denotes the maximum radial misalignment of each recording layer, $\Delta_{k,k+1}$ denotes the thickness of the spacer material between the subsequent layers Lk and Lk+1, and n_m is the refractive index of the spacer material, and that the first portions of said plurality of recording layers has the form of a staircase.

The invention takes into account that in write-once multi-layer media, preferably recording will be done layer-by-layer. Also in re-writable multi-layer discs this writing sequence may apply. The most logical implementation for layer-by-layer recording is top-to-bottom or bottom-to-top. By defining staircase shaped portions, the effect of data in higher-lying layers and absence of data in lower-lying layers, and vice versa, can be mimicked in the OPC-procedure. This has the advantage that every time – both during OPC and during user data recording – the same situation, that is reflection and/or transmission from above and below situated layers, is encountered when testing and recording the subsequent layers, thereby occupying a minimum space on the disc.

The width of the steps in the staircase is chosen such that it ensures that during the OPC-procedure stray-light from higher-lying layers with respect to an incident light beam is always from portions representative for recorded areas, while stray-light from lower-lying layers is always from portions representative for unrecorded areas, or vice versa, depending on the preferred order in which the layers are to be recorded.

According to a second aspect of the present invention which constitutes a further development of the first aspect, said optimum power calibration areas are arranged near the centre of said disc, said first portions thereby forming concentric circles.

According to a third aspect of the present invention which constitutes a further development of the first aspect, said optimum power calibration areas are arranged near the periphery of said disc, said first portions thereby forming concentric circles.

According to a fourth aspect of the present invention which constitutes a further development of the second or third aspects, the radiuses of the concentric circles decrease from recording layer to recording layer with respect to the direction away from the light beam incident side of said disc.

According to a fifth aspect of the present invention which constitutes a further development of the second or third aspects, the radiuses of the concentric circles increase from recording layer to recording layer with respect to the direction away from the light beam incident side of said disc.

Furthermore, according to a sixth aspect of the present invention, the above object of the invention is achieved by a method for forming optimum power calibration areas on a writable optical disc, said record disc comprising a plurality of recording layers L0,..., Ln-1 separated by a spacer material, wherein marks are written on said recording layers by means of a recording device with an objective lens having an aperture NA, thereby forming an optimum power calibration area on each of the recording layers, in such a way that at least the optimum power calibration areas of the layers L0,..., Ln-2 or L1,..., Ln-1 have a first portion with an average reflection value representative for a recorded layer, the optimum power calibration areas of each recording layer L0,..., Ln-1 have a second portion with an average reflection value representative for an unrecorded layer, and said optimum power calibration areas partially overlap in such a way that the first portions of each pair of subsequent recording layers Lk, Lk+1 form a step with minimum step size of

$$w_{k,k+1} = 2\varepsilon + \frac{NA}{\sqrt{n_m^{\ 2} - NA^2}} \cdot \Delta_{k,k+1},$$

wherein ε denotes the maximum radial misalignment of each recording layer, $\Delta_{k,k+1}$ denotes the thickness of the spacer material between the subsequent layers Lk and Lk+1, and n_m is the refractive index of the spacer material, and that and the first portions of said plurality of recording layers has the form of a staircase.

According to a seventh aspect of the present invention which constitutes a further development of the sixth aspect, said optimum power calibration areas are written near the centre of said disc, said first portions thereby forming concentric circles.

According to an eighth aspect of the present invention which constitutes a further development of the sixth aspect, said optimum power calibration areas are written near the periphery of said disc, said first portions thereby forming concentric circles.

According to an ninth aspect of the present invention which constitutes a further development of the seventh or eighth aspects, the optimum power calibration areas are written in such a way that the radiuses of the concentric circles decrease from recording layer to recording layer with respect to the direction away from the light beam incident side of said disc.

According to a tenth aspect of the present invention which constitutes a further development of the seventh or eighth aspects, the optimum power calibration areas are written in such a way that the radiuses of the concentric circles increase from recording layer to recording layer with respect to the direction away from the light beam incident side of said disc.

Furthermore, according to an eleventh aspect of the present invention, the above object is achieved by an apparatus arranged for recording data on a writable optical disc, said disc comprising a plurality of recording layers L0,..., Ln-1 having a maximum radial misalignment ε and being separated by a spacer material having a thickness $\Delta_{k,k+1}$ between two subsequent layers Lk, Lk+1 and a refractive index n_m, said apparatus comprising a writing unit with an objective lens having an aperture NA, said writing unit being arranged for writing marks on said recording layers, a controlling unit arranged for controlling said writing unit in such a way that marks are written at predetermined positions of said recording layers, thereby forming an optimum power calibration area on each of the recording layers, whereby at least the optimum power calibration areas of the layers L0,..., Ln-2 or L1,..., Ln-1 have a first portion with an average reflection value representative for a recorded layer, the optimum power calibration areas of each recording layer L0,..., Ln-1 have a second portion with an average reflection value representative for

an unrecorded layer, and said optimum power calibration areas partially overlap in such a way that the first portions of each pair of subsequent recording layers Lk, Lk+1 form a step with a minimum step size of

$$w_{k,k+1} = 2\varepsilon + \frac{NA}{\sqrt{n_m{}^2 - NA^2}} \cdot \Delta_{k,k+1},$$

and that the first portions of said plurality of recording layers has the form of a staircase.

The information corresponding to the a maximum radial misalignment ε of each recording layer, the thickness $\Delta_{k,k+1}$ of the spacer material between two subsequent layers Lk, Lk+1, and the refractive index n_m of the spacer material may be stored on the record carrier itself. For example, in case of a standard WORM or re-writable CD or DVD it may be part of the information stored as a modulated wobble signal in the pre-groove of the disc. Alternatively, the information may be stored as (pre-)recorded data in the lead-in-track or elsewhere on the disc.

In this case, according to a twelfth aspect of the present invention which constitutes a further development of the eleventh aspect, said apparatus further comprises means for deriving information from said writable optical disc corresponding to the a maximum radial misalignment ε of each recording layer, the thickness $\Delta_{k,k+1}$ of the spacer material between two subsequent layers Lk, Lk+1, and the refractive index n_m of the spacer material.

According to a thirteenth aspect of the present invention which constitutes a further development of the eleventh aspect, said controlling unit is further arranged for storing information corresponding to the maximum number of tracks recorded in the second portion of any layer during an OPC-procedure and further for writing marks on the other layers in such a way that the same number of tracks are recorded in the second portion of the OPC areas of all layers.

The above and other objects, features and advantages of the present invention will become apparent from the following description of preferred embodiments thereof, taken in conjunction with the accompanying drawings in which

Fig. 1 shows a cross sectional schematic view of multi layer disc with staircase shaped OPC-areas during an OPC operation;

Fig. 2 shows a cross sectional schematic view of multi layer disc with staircase shaped OPC-areas during an OPC operation in a different state;

Fig. 3 shows a schematic plan view of the maximum misalignment of two recording layers in a multi layer disc;

Fig. 4 is a cross sectional cut-out of a multi layer disc with n recording layers illustrating the first layer L_0 and last layer L_{n-1}; and

Fig. 5 is a cross sectional cut-out of a multi layer disc with n recording layers illustrating a pair of subsequent layers L_i and L_{i-1};

In Fig. 1 a cross section of a first embodiment of a writable optical record carrier according to the present invention is shown. The writable optical record carrier in this case is a multi layer disc 100 comprising four recording layers L0 through L3, wherein, L0 indicates the first layer and L3 the deepest layer with respect to an incident light beam. In other words, L0 defines the light beam incidence side of the disc. Each layer L0 to L3 comprises an OPC-area 101, 111, 121, and 131, respectively. Each of the OPC-areas except that of the deepest layer L3 has a first portion 102, 112, and 122, respectively, with an average reflection value representative for a recorded layer. Each of the OPC-areas except that of the first layer L0 has a second portion 113, 123, and 133, respectively, with an average reflection value representative for an unrecorded layer. Further, each recording layer L0 to L3 comprises an unwritten data area 104, 114, 124, 134 for storing controlling data or user data. An OPC-test laser beam 106 is shown in Fig. 1 entering the disc from this incidence side. Arrows 105, 115, 125 indicate stray light being reflected at the first portions of the OPC-areas of the out-focus layers L0 to L2 while the beam 106 is focussed on the deepest layer L3. In this case it is sufficient to provide layers L0, L1, L2 with first portions, only. Nevertheless the layer L3 may also be provided with a first portion having an average reflection value representative for a recorded layer.

In Fig. 2 the same embodiment of a 4-layer disc 200 is shown. The OPC-test laser beam 206 in this case is focussed on the second layer L1 of the disc 200 while arrows 205, 225, 235 indicate the light being reflected at the out-focus layers L0, L2, and L3. More precisely the light is reflected at the first (written) portion 212 of the OPC-area of L0 and at the second (unwritten) portions 223, 233 of the OPC-areas of L2 and L3, respectively.

From both Figs. 1 and 2 it can be seen that the OPC-areas are arranged partially overlapping in such a way that the first portions of the OPC-areas of each pair of subsequent recording layers form a step and that the OPC-areas of said plurality of recording layers has the form of a staircase. In accordance with their shape these areas are also referred to as staircase areas.

The direction of the staircase areas is defined by the order of recording the layers (top-to-bottom or bottom-to-top). In the embodiment shown in Figs. 1 and 2 the order of recording is top-to bottom (L0 to L3). If reverse order of recording (bottom-to-top) is preferred it would be sufficient to provide layer L1, L2, L3 with first portions, only.

Usually, the OPC procedure is executed by a customary optical disc recorder before the actual recording process since it is not acceptable that, e.g. during real-time recording of a movie, a layer-jump requires a new OPC procedure to be performed because it will result in loss of part of the movie. Therefore, the OPC-areas should be present before the OPC procedure starts. It can be generated either by means of the recorder itself by writing suitable marks, e.g. when a "virgin" disc is mounted on the recorder the first time, or it can be pre-recorded (ROM) on a ready-made disc. In the former case a controlling unit may be provided in the recorder arranged for executing an OPC-area writing process before the OPC procedure starts if the recorder determines that no OPC-areas exist. Consequently, e.g. "dummy data" to be written by the writing unit may be stored in a table or memory of the recorder. The controlling unit further may be arranged for controlling the writing unit to generate a writing beam modulated according to the stored dummy data. Then, marks are written at predetermined positions on the layers (in the example shown in Figs. 1 and 2, on the layers L0, L1, L2, only) of the disc, thereby forming a first portion of an optimum power calibration area on each of these layers having an average reflection value representative for a recorded layer.

It is to be noted, that the data quality in the OPC-areas, both written by the recorder and pre-recorded, is not important. However, it should contribute to an average reflection value representative for a recorded layer, e.g. 75% reflectivity of an unwritten initial state layer and 25 % reflectivity of a written (bleached or amorphous) area.

In the following we consider the OPC-areas near the inner-radius R_{min} (centre) of the disc and for the case of top-to-bottom recording with respect to the laser incidence side of the disc. The invention as well applies to bottom-to-top recording. Further, the following argumentation can be extended to any other radius, preferably to OPC-areas near the outer radius R_{max} (periphery) of the disc in a straightforward manner.

In order to make sure that during OPC and during user data recording the same situation (reflection/transmission by/through above and below layers) is encountered the minimum step width is determined next. Thereby two effects are considered the misalignment or eccentricity of the layers and the opening-angle of the light cone of the incident laser beam.

The incident reading or writing light beam is focussed by an objective lens of the reading/writing unit of the recorder. Thereby, a light cone is generated having an opening angle θ defined by the numerical aperture NA of the objective lens. It is

$$NA = n_m \times \sin(\Theta), \tag{2}$$

wherein n_m is the refractive index of the medium through which the light propagates, e.g. the spacer material which separates the recording layers.

On an out-focus layer that is located at distance Δ a spot radius R of

$$R = \Delta \times \frac{\sin^2(\Theta)}{\sqrt{1-\sin^2(\Theta)}} = \Delta \times \frac{NA}{\sqrt{n_m^2 - NA^2}} \tag{3}$$

is generated. In order to guarantee that the OPC-test beam always passes higher lying layers having an average reflectivity representative for a recorded layer (top-to-bottom recording) the minimum width of the staircase areas is determined by this radius R.

So far, a possible misalignment of the layers has not been taken into account. The layers in a multi-layer disc should be aligned with respect to a reference point, e.g. the ideal geometrical centre of gravity of the disc. The tolerance in positioning of the individual layers, in other words the eccentricity of the pre-groove spiral of the layers, with respect to this reference point is ε. This implies that any pair of layers in the multi-layer disc is at most displaced by +2ε, or –2ε, with respect to each other, see Figure 3. Inner radiuses R_{min} 302 and 312 of the OPC-areas of two exemplary layers are shown. Their centres 304, 314 are displaced by +2ε (to the right) and –2ε (to left). To correct for maximum possible misalignment or eccentricity an additional increment of 2ε for the width of the staircase areas of subsequent layers should be taken into account as will be shown below.

The start position of the OPC area on the deepest layer Ln-1 of a n-fold layered disc is defined as $R_{OPC,Ln-1}$. When Ln-1 is in focus, the width of the spot $w_{Ln-1,L0}$ on the first layer L0 with respect to the incident light can be calculated according to the formula (3) given above. To ensure that the light-cone 406 is fully captured by a written first portion 402 in L0 when performing OPC on the unwritten second portion 433 in Ln-1, the second portion of the OPC-area in Ln-1 should start at

$$R_{\min,Ln-1} + 2\varepsilon + \Delta_{tot} \times \frac{NA}{\sqrt{n_m^2 - NA^2}}, \tag{4}$$

where Δ_{tot} is the total vertical distance between Ln-1 and L0 (the summed thickness of all spacers), see Fig. 4.

Furthermore, to ensure that the light-cone 506 of a beam focussed on a layer Lk+1 fully passes a recorded first portion 502 in the next higher layer Lk when performing OPC on the unwritten second portion 523 in Lk+1, the step size $w_{k,k+1}$ between the first portions of two subsequent layers Lk and Lk+1 should be

$$w_{k,k+1} = 2\varepsilon + \frac{NA}{\sqrt{n_m{}^2 - NA^2}} \cdot \Delta_{k,k+1} \tag{5}$$

where $\Delta_{k,k+1}$ is the spacer thickness between subsequent layers, see Figure 5. Note that $\Delta_{k,k+1}$ may vary between different layers.

These considerations imply that in an n-layer disc the following equation should be obeyed for the minimum width w_i of the first portion of the OPC-area of each layer Li (i= 0 … n – 1):

$$\begin{aligned} w_i &= 2\varepsilon + \frac{NA}{\sqrt{n_m{}^2 - NA^2}} \cdot \sum_{k=0}^{n-2} \Delta_{k,k+1} \\ &\quad + (1 - \delta_{i,n-1}) \cdot \sum_{k=i}^{n-2} \left[2\varepsilon + \frac{NA}{\sqrt{n_m{}^2 - NA^2}} \cdot \Delta_{k,k+1} \right] \end{aligned} \tag{6}$$

Herein, $\Delta_{k,k+1}$ is the spacer thickness between the layers k+1 and k. Note, that the first summation corresponds to the total spacer thickness Δ_{tot} between Ln-1 and L0, and that the last summation vanishes for i = n–1 due to the Kronecker delta-function $\delta_{i,n-1}$. Note, that the deepest layer Ln-1 does not require a first portion having an average reflection value corresponding to a recorded layer since there is no deeper layer to be focussed. Therefore, w_{n-1} can also be set to 0. Further, the first layer L0 does not require a second portion having an average reflection value corresponding to an unrecorded layer since the OPC-procedure, if necessary, can also be execute in the user data area of the first layer. Therefore the maximum width of the OPC-area can be limited to w_0.

The number of tracks in the first portions of the OPC-areas that need to contain (dummy) data is obtained by dividing the step width by the track pitch.

The second portions of the OPC-areas, that is where the OPC-procedure takes place in a layer, are always defined adjacent to the first portions thereof. This ensures that for multiple OPC procedures on a single disc the requirements for data (no data) in the higher (lower) lying out-focus layers is met, particularly, when each OPC on each layer uses the same number of tracks. The total length available for the OPC area may be set by other requirements.

When during an OPC-procedure new test data are written in the second portion of the OPC-area of any layer, the condition of the minimum step size may no longer be met. Therefore, in a further embodiment of the invention the apparatus for recording is arranged to (temporarily) store information corresponding to the maximum number of tracks (or data blocks) recorded on this layer during the OPC-procedure. Further, it is arranged to record data or marks causing average reflection value representative for a recorded layer on the other layers in such a way that on all layers the same amount of tracks (data blocks) are recorded in the second portion of the OPC areas.

For example, in dual-layer DVD+R with NA = 0.65, $n_m = 1.55$, $\Delta = 50$ µm, $2\varepsilon = 70$ µm, and OPC-areas at the inner diameter of the disc according to equation (6) we obtain the following results: The first portion inner diameter of the second portion of the OPC area in L1 (deepest layer) starts at a width of

$w_1 = 70 + 0.46*50 = 93$ µm = 126 tracks

counted from the start (inner diameter) of the L1 track at $R_{min,L1}$. For L0 (first layer) the width of the first portion of the OPC-area counts

$w_0 = 70 + 0.46*50 + 70 + 0.46*50 = 186$ mm = 251 tracks

from the start of the L0 track at $R_{min,L0}$. The second portion of the OPC area in L0 starts right behind w_0.

In quadruple-layer DVD+R with NA = 0.65, $n_m = 1.55$, $\Delta = 50$ µm, $2\varepsilon = 70$ µm. Then, and OPC-areas at the inner diameter of the disc according to equation (6) we obtain the following results:

$w_3 = 70 + 0.46*150 + 70 + 0.46*50 = 139$ mm = 282 tracks,

$w_2 = 70 + 0.46*150 + 70 + 0.46*50 + 70 + 0.46*50 = 232$ mm = 314 tracks,

$w_1 = 70 + 0.46*150 + 70 + 0.46*50 + 70 + 0.46*50 + 70 + 0.46*50 = 325$ mm = 439 tracks,

and

$w_0 = 70 + 0.46*150 + 70 + 0.46*50 + 70 + 0.46*50 + 70 + 0.46*50 + 70 + 0.46*50 = 418$ mm = 565 tracks.

Each width w_i counted from the start (inner diameter) of the correponding track at $R_{min,Li}$.

The second portions of the OPC areas again start subsequent to their first portions.

In the same embodiments as above but for OPC-areas at the outer diameter of the disc results with the same absolute values for w_i are obtained but with negative signs. Consequently, each width w_i is counted from the end (outer diameter) of the correponding

track at $R_{max,Li}$. In this case, the OPC should preferably be performed from the outer diameter towards inner diameter.

In an embodiment of the invention, the written effects in the staircase area contain control information.

It should be noted that this invention is not limited to an optical record carrier comprising 2 or 4 layers, but also applies a record carrier comprising 3, 5, and more layers. It is furthermore not limited to inner or outer diameter OPC-areas, but may apply to any other arrangement of OPC-areas as well.

CLAIMS:

1. Writable optical disc for use in a recording device with an objective lens having an aperture NA comprising a plurality of recording layers L0,…, Ln-1 separated by a spacer material, each of the recording layers comprising an optimum power calibration area, whereby at least the optimum power calibration areas of the layers L0,…, Ln-2 or L1,…, Ln-1 have a first portion with an average reflection value representative for a recorded layer, the optimum power calibration areas of each recording layer L0,…, Ln-1 have a second portion with an average reflection value representative for an unrecorded layer, and said optimum power calibration areas partially overlap in such a way that the first portions of each pair of subsequent recording layers Lk, Lk+1 form a step with a minimum step size $w_{k,k+1}$ of

$$w_{k,k+1} = 2\varepsilon + \frac{NA}{\sqrt{{n_m}^2 - NA^2}} \cdot \Delta_{k,k+1},$$

wherein ε denotes the maximum radial misalignment of each recording layer, $\Delta_{k,k+1}$ denotes the thickness of the spacer material between the subsequent layers Lk and Lk+1, and n_m is the refractive index of the spacer material, and that the first portions of said plurality of recording layers has the form of a staircase.

2. Writable optical disc according to claim 1, characterized in that said optimum power calibration areas are arranged near the centre of said disc, said first portions thereby forming concentric circles.

3. Writable optical disc according to claim 1, characterized in that said optimum power calibration areas are arranged near the periphery of said disc, said first portions thereby forming concentric circles.

4. Writable optical disc according to claim 2 or 3, characterized in that the radiuses of the concentric circles decrease from recording layer to recording layer with respect to the direction away from the light beam incidence side of said disc.

5. Writable optical disc according to claim 2 or 3, characterized in that the radiuses of the concentric circles increase from recording layer to recording layer with respect to the direction away from the light beam incidence side of said disc.

6. Method for forming optimum power calibration areas on a writable optical disc, said disc comprising a plurality of recording layers L0,..., Ln-1 separated by a spacer material, wherein marks are written on said recording layers by means of a writing recording device with an objective lens having an aperture NA, thereby forming an optimum power calibration area on each of the recording layers, in such a way that at least the optimum power calibration areas of the layers L0,..., Ln-2 or L1,..., Ln-1 have a first portion with an average reflection value representative for a recorded layer, the optimum power calibration areas of each recording layer L0,..., Ln-1 have a second portion with an average reflection value representative for an unrecorded layer, and said optimum power calibration areas partially overlap in such a way that the first portions of each pair of subsequent recording layers Lk, Lk+1 form a step with minimum step size of

$$w_{k,k+1} = 2\varepsilon + \frac{NA}{\sqrt{n_m{}^2 - NA^2}} \cdot \Delta_{k,k+1},$$

wherein ε denotes the maximum radial misalignment of each recording layer, $\Delta_{k,k+1}$ denotes the thickness of the spacer material between the subsequent layers Lk and Lk+1, and n_m is the refractive index of the spacer material, and that the first portions of said plurality of recording layers has the form of a staircase.

7. Method according to claim 6, characterized in that said optimum power calibration areas are written near the centre of said disc, said first portions thereby forming concentric circles.

8. Method according to claim 6, characterized in that said optimum power calibration areas are written near the periphery of said disc, said first portions thereby forming concentric circles.

9. Method according to claim 7 or 8, characterized in that said optimum power calibration areas are written in such a way that the

radiuses of the concentric circles decrease from recording layer to recording layer with respect to the direction away from the light beam incidence side of said disc.

10. Method according to claim 7 or 8, characterized in that said optimum power calibration areas are written in such a way that the radiuses of the concentric circles increase from recording layer to recording layer with respect to the direction away from the light beam incidence side of said disc.

11. Apparatus arranged for recording data on a writable optical disc, said disc comprising a plurality of recording layers L0,..., Ln-1 having a maximum radial misalignment ε and being separated by a spacer material having a thickness $\Delta_{k,k+1}$ between two subsequent layers Lk, Lk+1 and a refractive index n_m, said apparatus comprising

a writing unit with an objective lens having an aperture NA, said writing unit being arranged for writing marks on said recording layers,

a controlling unit arranged for controlling said writing unit in such a way that marks are written at predetermined positions of said recording layers, thereby forming an optimum power calibration area on each of the recording layers, whereby at least the optimum power calibration areas of the layers L0,..., Ln-2 or L1,..., Ln-1 have a first portion with an average reflection value representative for a recorded layer, the optimum power calibration areas of each recording layer L0,..., Ln-1 have a second portion with an average reflection value representative for an unrecorded layer, and said optimum power calibration areas partially overlap in such a way that the first portions of each pair of subsequent recording layers Lk, Lk+1 form a step with a minimum step size of

$$w_{k,k+1} = 2\varepsilon + \frac{NA}{\sqrt{n_m^{\ 2} - NA^2}} \cdot \Delta_{k,k+1},$$

and that the first portions of said plurality of recording layers has the form of a staircase.

12. Apparatus according to claim 11, characterized in that said apparatus further comprises

means for deriving information from said writable optical disc corresponding to the a maximum radial misalignment ε of each recording layer, the thickness $\Delta_{k,k+1}$ of the

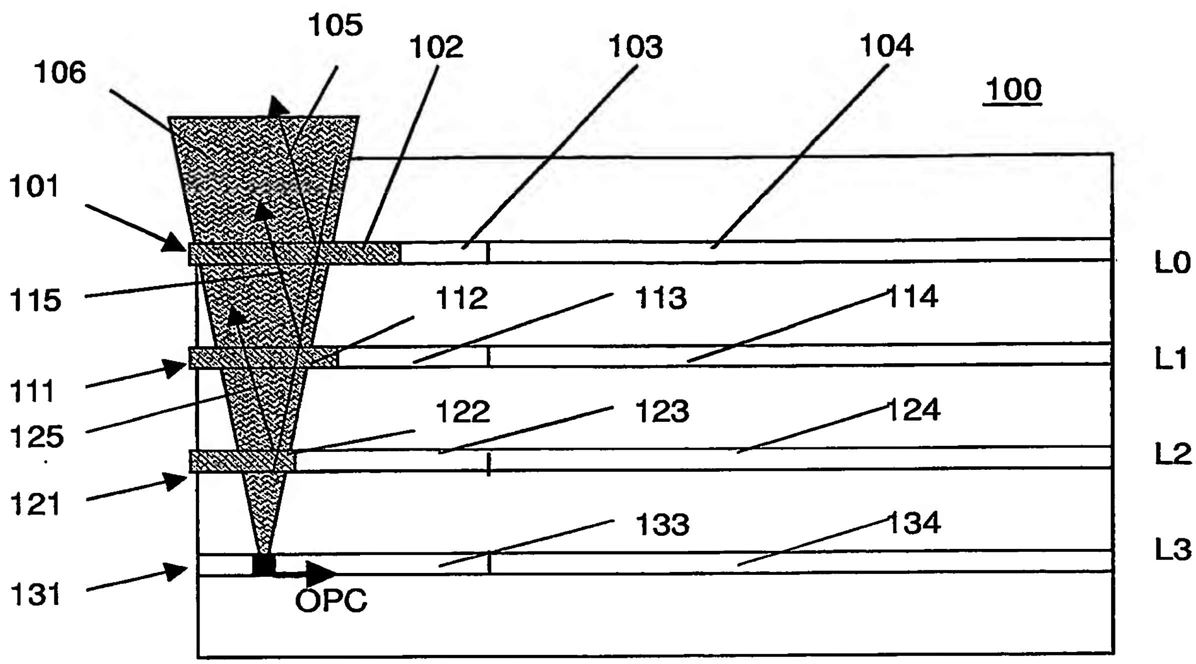
spacer material between two subsequent layers Lk, Lk+1, and the refractive index n_m of the spacer material.

13. Apparatus according to claim 11, characterized in that said controlling unit is further arranged for storing information corresponding to the maximum number of tracks recorded in the second portion of any layer during an OPC-procedure and further for writing marks on the other layers in such a way that the same number of tracks are recorded in the second portion of the OPC areas of all layers.

ABSTRACT:

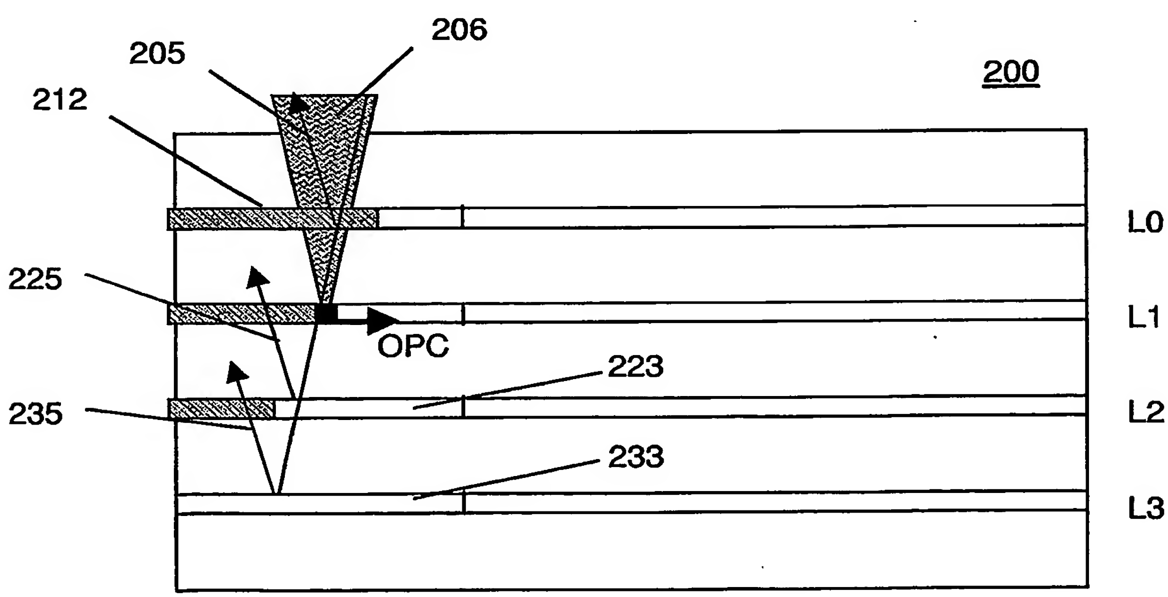
A writable optical record carrier comprising a plurality of recording layers L0,..., Ln-1 separated by a spacer material, each recording layer comprising an optimum power calibration area having a first portion with an average reflection value representative for a recorded layer and a second portion with an average reflection value representative for an unrecorded layer, a method, and an apparatus for forming optimum power calibration areas on such a writable optical record carrier are presented. The optimum power calibration areas partially overlap in such a way that the optimum power calibration areas of each pair of subsequent recording layers form a step and the first portions of said plurality of recording layers has the form of a staircase. Each step formed by a pair of subsequent recording layers k, k+1 has a preferred minimum step size.

Fig. 1 to be added.



105
102
103
104
106
100
101
L0
115
112
113
114
L1
111
125
122
123
124
L2
121
133
134
L3
131
OPC

FIG.1



206
205
200
212
L0
225
L1
OPC
223
235
L2
233
L3

FIG.2

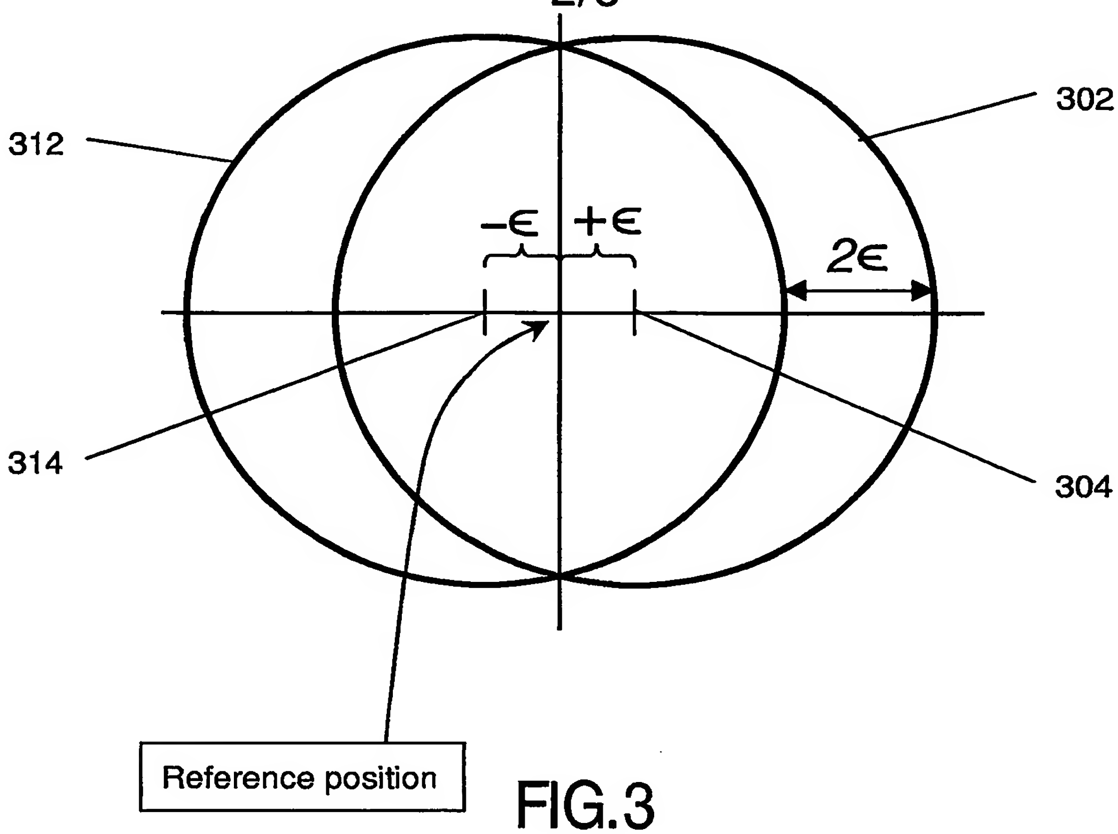

312
302
$-\epsilon$
$+\epsilon$
2ϵ
314
304
Reference position

FIG.3

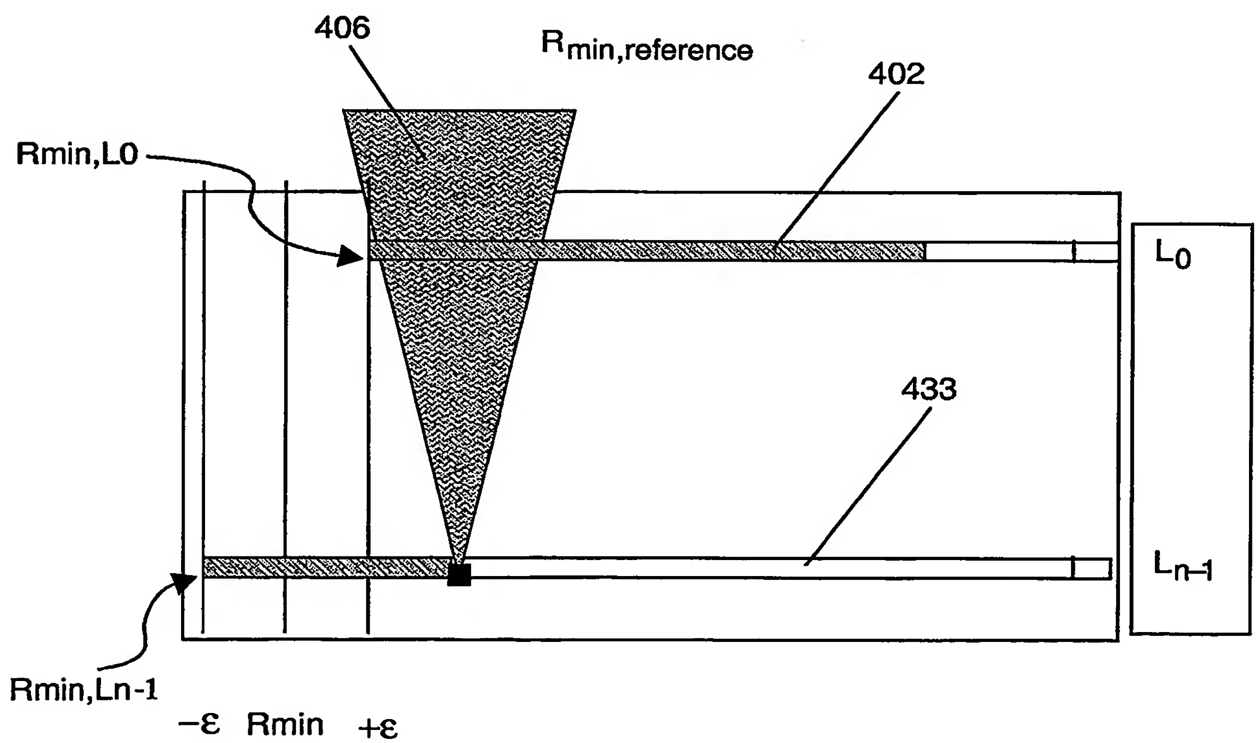

406
$R_{min,reference}$
402
Rmin,L0
L_0
433
L_{n-1}
Rmin,Ln-1
$-\varepsilon$ Rmin $+\varepsilon$

FIG.4

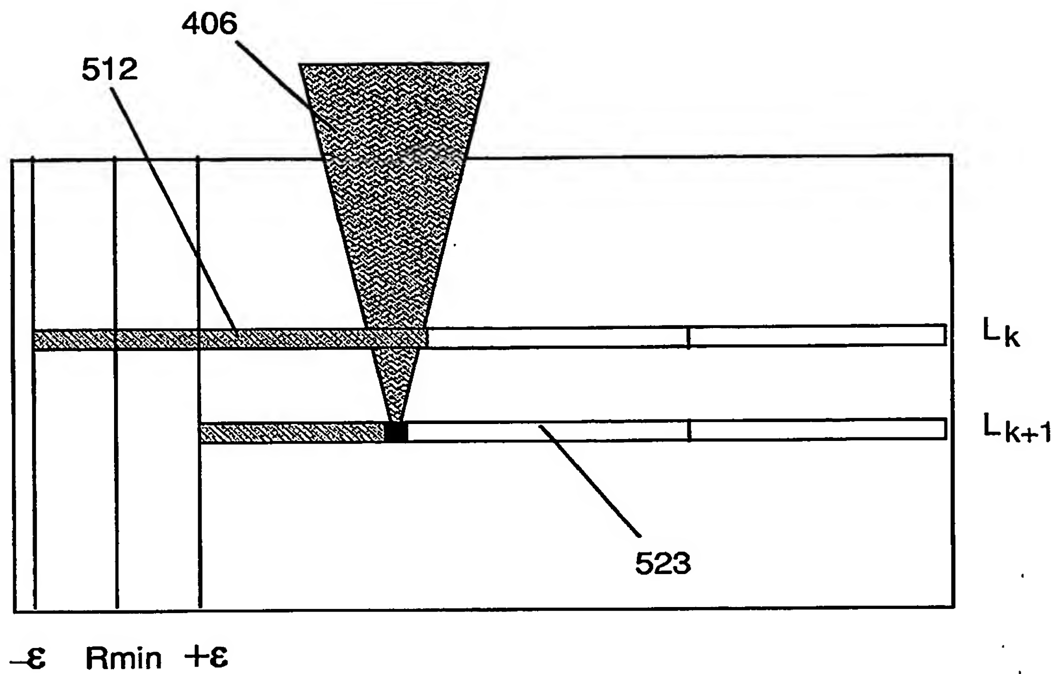


FIG.5